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REPORT ON TESTS OF THE UNDERWATER SOUND INTENSITY METER FOR LOCATING TRANSITORY SOURCES

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Magnolia Petroleum Company
Field Research Laboratories
Dallas, Texas

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ABSTRACT

Operation of an underwater acoustic intensity meter was studied as transient energy from splashes and explosions passed the detectors. Several inherent features of the instrument which make it attractive for directive listening were demonstrated. It indicated the direction of flow of the energy burst within approximately 5° when ships and other steady sources of background noise were present and when one transient signal followed another by more than 0.1 second. The six inch diameter detector assembly operating in the frequency band between 20 and 500 cps did not have to be rotated or scanned to obtain bearings. The tests support the possibility that the instrument can be used as a splash locator for harbor defense against aerially laid mines and that it would be a useful tool for studying low frequency underwater sound transmission.

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REPORT ON TESTS OF THE UNDERWATER SOUND INTENSITY METER FOR LOCATING TRANSITORY SOURCES

I. INTRODUCTION

A. General

An acoustic intensity meter for use in water is being developed at the Field Research Laboratories of the Magnolia Petroleum Company in Dallas under Contract Nonr-680(00) with the Office of Naval Research. The underwater detector used with this device includes a barium titanate cylinder which generates a voltage proportional to sound pressure at a point and three geophones (the type ordinarily used in seismic prospecting for oil) which generate voltages proportional to the components of particle velocity in three perpendicular directions. Electronic multipliers developed on the contract for use in the instrument multiply the pressure signal by each of the velocity signals separately, and average the products, thus providing three voltages which are proportional to the rate of transfer of acoustic energy in three directions. These three voltages represent the components of a vector which when combined give the magnitude and direction of the rate of acoustic energy flow relative to the directions along which the geophones are oriented. When the sound field is due to one principle source of sound, this vector points toward the source. It is this fact which suggested that an intensity-measuring device might have military application as a directional detector.

B. Instrument Characteristics

1. Advantages

The instrument has several features that make it attractive for listening applications. Its directivity is independent of frequency as

long as the wave length of the sound is large compared to the size of the detectors. This is quite different from spaced pressure detector systems and suggests that the intensity meter can be profitably used on low frequency sounds. The detectors are effectively searching in all directions all the time so the system requires no mechanical or equivalent electronic scanning arrangement. Operation should be satisfactory when the signal-to-noise ratio at the detectors is low. Sound from ambient sea noise sources arriving at the detectors from random directions will produce no net energy flow and an output is produced only when a source in a fixed direction causes a steady flow. Since the instrument output indication is not related to the input wave shape, constant intensity from nearby sources can be cancelled to prevent masking distant sources by injecting sinusoidal signals into the measuring system. Then operation can proceed as if only the distant source were present.

2. Disadvantages

An inherent disadvantage of the instrument is that it cannot resolve multiple sources producing similar sounds at the same time. It measures the total intensity at a point, but this vector is not necessarily directed toward any particular source when it is the summation of the intensities from several sources. At first glance this would seem to eliminate any practical usefulness for the intensity meter, since it could not track a particular ship when others were operating in the area. It is felt, though, that there are several situations of military importance in which the detectors can be operated well away from disturbing sound sources and other cases in which the character of a particular sound distinguishes it

from others in the area sufficiently to make it detectable.

C. Possible Applications

1. For Locating Steady Sources

A situation where there would be no disturbing sources might arise in tracking the movements of enemy submarines or shipping not directly engaged at the time in making an attack. In this case the intensity meter could be operated aboard a lone submarine or on a sonobuoy. It could be assumed there were no friendly noise makers about and the only thing causing an intensity indication would be the enemy. The advantages of using the intensity meter could be realized and multiple sources would not have to be resolved. A sonobuoy equipped with an intensity meter would have the advantage of being small and directive and would respond to the low frequency sounds that travel greater distances before being attenuated below a detectable level.

2. For Locating Transitory Sources

It seems likely that the sound produced by splashes and explosions would be distinguishable from that produced by ships because of its transient nature and could therefore be detected by the intensity meter even when ship noise was present. In this case, when just transient signals are being studied, resolving multiple sources is a problem only in the unlikely circumstance that energy bursts from two sources arrive at the detector simultaneously. This suggests the profitable use of the intensity meter in harbor defense work for locating splashes due to aerially laid mines and also the possibility of using it as a receiver in a low frequency sonar system.

D. Operational Tests

1. Laboratory Tests

The intensity meter was constructed and tested first in an air duct. The detectors were located in the center of the duct and the direction of flow of energy was indicated as standard loud speakers at the ends transmitted sound in either direction along the duct. A sinusoidal sound wave from the speaker at one end cancelled the instrument indication produced by a noise signal from the other end to prove that intensity was being measured. When only one speaker was turned on to produce either a complex or sinusoidal traveling wave the directional properties of the detectors were demonstrated. The relative bearing to the sound source was changed by rotating the detectors. The instrument always pointed to the source of the sound.

2. Lake Tests

Underwater operation of the detectors was first investigated at the Travis Lake facility of the Defense Research Laboratory in Austin, Texas. Here the detectors were elastically suspended from a tripod planted on the lake bottom. The instrument successfully tracked a "target" boat and operated in every respect as expected. These tests under conditions of minimum ambient noise and with the detectors on a very stable mounting showed that sea tests were in order.

3. Sea Tests

Technical Report No. 680(00)-1, "The First Sea Tests of the Underwater Intensity Meter" by J. F. White reported tests conducted in cooperation with the Naval Electronics Laboratory at San Diego, California.

These were intended to be a preliminary evaluation of the device for long range listening applications. The detectors operated satisfactorily when they were suspended above the deck of a submarine hovering at periscope depth and the instrument tracked one surface vessel for approximately 25 minutes with fair accuracy. Disturbing traffic in the test area prevented accumulating sufficient data to evaluate the bearing accuracy of the instrument or to permit estimating the range at which ships can be detected. The tracking that was done and successful operation of the detectors on the deck support the probability that the intensity meter is suitable for long range listening. Complete evaluation tests in an area with less traffic seem advisable, but they have not been conducted yet.

4. Harbor Tests

First attempts to use the intensity meter for locating transient signals were made this past summer at Beavertail Point near Jamestown, Rhode Island. The work was done in cooperation with the Harbor Defense Research Unit located there and is reported in this document. For these tests two complete systems were used and the energy bursts from splashes and explosions were measured at two points. The two pickup assemblies were planted approximately 900 feet apart on the bottom of the channel between Jamestown Island and the mainland in Narragansett Bay. Pressure variations and the horizontal components of both velocity and intensity at each of the pickup positions were recorded for study. These records, several of which are presented, show how the quantities vary with time as

the energy from the disturbance passes the pickups and provide a good demonstration of how the intensity meter operates. On some of the records when boats were making steady noise in the area the intensity traces clearly show the improvement in signal-to-noise ratio obtained by measuring intensity. The recorded intensity variations also provide information on the travel path of the energy from the source to the detectors that would be very difficult to obtain otherwise and they were used to calculate the bearings of the sources. Good bearing accuracy and the other results obtained indicate that the intensity meter is suitable for locating splashes and for studying the low frequency characteristics of transient sounds. Incorporation of equipment for automatically recording splash signals when they occur is recommended to make the system one that can be used for continuous monitoring purposes.

The tests reported here were conducted by Stanley N. Heaps, Joseph Zemanek, Jr., and Robert L. Mills of the Magnolia Petroleum Company, with the direct assistance of LCDR Nathaniel H. Frade and Lt. Richard S. Edwards and with the cooperation of their staff at the Harbor Defense Research Unit at Beavertail Point. The cooperation of the other groups working at the facility, particularly the people from Yale University, who, in several instances, relinquished equipment for our benefit and thereby slowed down the work on their projects is also gratefully acknowledged.

The successful results of these tests make the profitable use of the intensity meter as a receiver in a low frequency sonar system seem very likely. This possibility should be investigated also.

II. INSTRUMENTATION

The instrumentation used during the trials at Beavertail Point differed from that used previously in three respects. First, special tripods which could be lowered from a boat and which insured proper operation of the geophones were used for suspending the detectors just above the bottom. Second, two systems were used with the detectors separated so that the position of the source could be found from the two bearing indications. And third, pressure, velocity, and intensity were recorded so thorough studies of the short lived signals would be possible. This section describes the instrument set-up and the intended function of the component parts.

Figure 1 is a sketch of the tripod assembly used. It is drawn with a section of the rubber current screen cut away so the approximate relative size and location of the detectors can be seen. Features intended to insure proper detector operation are: the rocker assembly at the top which will keep the supports for the detectors in a horizontal plane even though one of the tripod feet happens to land on a rock or other bottom irregularity as the tripod is planted; the neoprene sheet around the outside which shields the detectors from currents but does not interfere with the passage of a sound wave; and the 100 pound weights on the feet which keep the tripod from moving or tipping as currents push on the rubber shield. The assembly was made collapsible for easy transportation and was assembled on board ship just before the tripod was lowered to the bottom. A single line was attached at the very top of the rocker assembly for lowering, and the whole planting operation was performed from the surface.

Figure 2 is a cutaway sketch of the geophone assemblies. Since only the azimuth angle to the sound sources was to be measured only two geophones were used at each measurement point. These were oriented with their axes in a horizontal direction. The vertical component of velocity which would indicate the elevation of the source relative to the pickups was not measured. The cylindrical aluminum can around the geophones had air in the space not occupied by the geophones. This made the whole assembly have a density just slightly higher than that of water so it would move as nearly as possible with the water particles surrounding it. The geophones and the vertical member into which they were screwed produced a distribution of mass in the can so that sound forces would not cause rotation or tilting. This unit was suspended from two points so it could be kept turned in a fixed direction with the geophone axes horizontal. The suspension was elastic so vibrations of the tripod would not shake the geophones.

The pressure pickup consisted of a barium titanate cylinder with a rubber sleeve over the outside, brass plugs in each end, and an impedance changing preamplifier inside. It was mounted as close as practical to the geophones and supported by the same elastic cord. Its mass further decreased the natural resonance period of the suspension and thereby helped isolate the geophones from any tripod vibration.

Two of these complete detector assemblies were used. Their exact locations, obtained by surveying as they were being planted, are shown on the maps of Figures 15 and 16. Electrical cables from each set of detectors extended from the tripods to a junction box in the vicinity of the Number 1

(inshore) tripod and then one large cable carried the signals up to the house on shore where the electronic equipment was set up.

Two sets of electronic equipment such as the one shown in the block diagram of Figure 3 were used. Principle functions of the blocks can be tabulated as follows:

1. Compensator - This unit compensates for differences in the manner of operation of the two types of detectors. It adjusts the phase of the voltage in the pressure channel to have the same relation to the sound pressure in the water as the voltage in the velocity channels has to water velocity.

2. Amplifiers - These units amplify the detector output voltages by adjustable amounts and filter the signals as desired in the frequency band between 20 and 500 cycles per second. All signal amplifiers are identical. When measuring intensity the filters in all of them are set the same and the gains of the two velocity amplifiers are made equal.

3. Multipliers - These units produce the product of the pressure voltage and each velocity voltage. All the multipliers are identical. The details of their operation are described in Technical Memo No. 680(00)-4.

4. Integrating Filters - These average the multiplier outputs. The time constants of these circuits can be set on 0.1, 1, 2, 4, or 8 sec. Both filters in a system must be set the same when the travel direction of energy bursts is being indicated.

5. Choppers - These change the d.c. filter output signals to waves that have a zero value for a brief period once every sixtieth of a second and rise exponentially to a value proportional to the filter output between the zero valued periods. The two choppers in a system are synchronized so their outputs will effectively draw one line on the oscilloscope screen and the rate of rise of the chopped signals is the same so the line will be straight.

6. Oscilloscope - This displays a representation of the horizontal intensity vector. One component of the vector is applied to the horizontal deflecting plates and the other is applied to the vertical set. The deflection of the spot from the center of the screen is the vector sum of the two applied components. Therefore the distance is proportional to the intensity amplitude. The angle between a line from the spot to the center of the screen and the vertical axis of the cathode ray tube is the bearing angle of a sound source relative to the direction of one geophone axis. Relative bearings read directly from the oscilloscope face are simply added to the orientation angle of this geophone to obtain the true bearing to the sound source.

7. Impedance Changing Circuit - This unit couples the galvanometers in the recorder to the amplifiers and the multipliers. It contains transformers for this purpose in the pressure and velocity channels and d.c. amplifiers in the intensity channels. Also included are attenuators for changing the recording sensitivities in all channels and filters for setting the integrating times in the intensity channels. These filters are identical to the integrating filters of item 4. They were duplicated in this unit so intensity variations too rapid for use on the oscilloscope display could be recorded. The 0.1 sec. time constant was usually used for recording while longer time constants were needed to get a line from which you could read bearing angles on the oscilloscope.

8. Recording Oscillograph - This was a standard twelve channel seismic camera in which an applied voltage is represented by the position of a small beam of light. The light is reflected from a small mirror attached to the movement of a D'Arsonval type galvanometer. It strikes photosensitive paper to make a spot that moves across the paper as the voltage applied to the galvanometer varies. The paper is driven at a constant speed in a direction perpendicular to the direction of the light beam motion and developing it shows how the voltage applied to the galvanometer varied with time. The voltage response of the galvanometers used for this work was flat up to approximately 220 cycles per second with the damping provided by the driving circuits. The paper was driven at approximately 15 inches per second.

A timing circuit which produced a line clear across the paper every one-fiftieth of a second provided a means for measuring time intervals on the records.

No automatic equipment for starting the camera paper drive motor was available so it had to be started manually at the right time to record the desired signal. Methods of doing this and other techniques used during the tests are described in the next section.

III. TEST PROCEDURES

The tests consisted essentially of exploding dynamite caps or dropping mines in several different places and recording the received signals that resulted. Special techniques had to be worked out for (1) catching the signals on the fast moving recording paper without using too much paper, (2) for setting the amplifier gains and recording sensitivity to get records that were easy to interpret, and (3) for finding the splash and explosion locations by other means to check the accuracy of the intensity meter indications.

For the first of these, dynamite caps suspended by their electrical leads to a depth of approximately 15 feet were exploded by applying a voltage on a signal from the cameraman when he started the paper drive motor. In the case of splashes, the camera was started on a signal from an observer watching the mines fall from the airplanes. Synchronizing the starting of the camera with the occurrence of the signals in these ways made it possible to catch the desired signals someplace on an approximately three foot length of paper.

In the case of explosions, gain and sensitivity settings for getting good records were determined by trial and error. Several shots frequently had to be made in the same place to find the best settings. This was impossible in the case of splashes so some of the splash records were not as good as could have been obtained with other gain and sensitivity settings.

The locations of explosions were found by means of sextant readings between landmarks taken at the shot sites by the shooter. Splashes were located for us by photographic methods and radar. These splash location methods are also being developed at the Beavertail Laboratory and have been found to be accurate.

Most of the data recorded was on explosions. We had complete control of when and where this type of signal would be produced and the cost per explosion was nominal. In the case of splashes, on the other hand, considerable coordination was required to have airplanes drop mines in a specific area at a given time and the cost of the complete operation including retrieving the mines is relatively high. In spite of these disadvantages enough mines were dropped for us during the test period to show how our equipment responded to both types of transient signals.

IV. DESCRIPTION OF RECORDS

Several records on both types of signals will be presented. Figure 6 is a typical one. In most cases the information of interest was contained in approximately a foot of the total record so the extraneous parts were trimmed off and just the variations due to the splashes and explosions are presented. The trimmed off parts contained no information not typified by the short sections remaining before and after the signal. The vertical lines on the records are timing lines. As explained previously they are .02 sec. apart and represent the abscissa divisions on the time plots produced on the records. The top three lines, referred to as P_1, V_{1x}, and V_{1y} respectively moving down the record, are the signals from the inshore (number 1) detector assembly. The V_{1x} trace represents one component of velocity at this site and V_{1y} is the component at right angles to it. The subscripts x and y refer to the axes of the oscilloscope face along which the spot will move due to the velocity component. Similar measurement of pressure and velocity at the outboard (number 2) tripod were recorded as the next three traces down. Once again the order, moving down, is pressure and then the velocity components. The bottom four are intensity traces. The first two of these are the horizontal components of intensity at the number 1 site, the upper one (I_{1y}) being the product of P_1 and V_{1y}, the lower (I_{1x}) being the product of P_1 and V_{1x}. The last two traces are the comparable intensities at number 2 pickup.

Records such as these show how the measured quantities varied with time, when the traveling sound wave arrived at the two locations, how long the sound burst lasted, the principle frequencies present in the burst, the relative intensities of the signal at the two locations, and the direction of travel of the signal. Ambient background noise is most obvious before the signal arrives and after it nas passed. Also visible on the records in many cases were several, rather than just one, discreet packets of energy arriving from the source.

Detail interpretation of the recorded data was beyond the scope of this investigation, but the data was used to find the direction of travel of the energy. Three methods of finding the travel direction from the records are possible. First, the difference in the time of arrival of the energy at the two locations can be used; second, relative amplitudes of the two velocity signals at each measuring point can be used; and third, the relative intensities at the two points can be used. One of the primary objectives of the tests was to see if the third method gave accurate results so it was the one used most. The ratio of the amplitudes of the intensity components of one system were measured at an arbitrary instant and the angle whose tangent equaled this ratio was found. With proper consideration of the signs of the intensity components this is the indicated relative bearing angle. The indicated true bearing was then found by adding a correction to take the orientation of the detectors into account. Errors were found by comparing the indicated bearing with that found from information on the true location of the signal source.

V. RESULTS

Records and the bearings calculated from them are presented in this section. The indicated bearings are shown as directed lines on maps of the area. When more than one explosion was set off at one site only a typical record is shown, but bearing calculations based on every shot are presented.

Figures 4 to 10, inclusive, are the records obtained from dynamite cap explosions. The shot points are indicated on the map of Figure 15. For evaluating the intensity meter as a splash locator, the records were graded on the basis of signal amplitude, smoothness of the intensity curves, and repeatability. All of the ones from T-21 and T-21S (see Figures 4 and 5) were classed as poor. Better repeatability was obtained with the offshore shots at Danbuoys "Dog", "Easy", and "Fox", but low recording sensitivities and irregular intensity curves made the records from these shots only fair or worse. The best record from an explosion was one obtained from the location designated by us as "Getty". It is interesting to observe that this record (Figure 10) obtained during a rain shower was from the most distant explosion set off during the tests. The range of the walky-talkies used for communication between the camera operator and the shooter, and not weak signals, was the factor that limited this distance to 4200 yards.

The records of Figures 11 to 14, inclusive, show the signal variations due to mine splashes. The record of the one to the south of the pickups and the third one to the west were of good quality. Mines

were dropped at ever increasing distances south of the one which produced the first of these, but we got no records of them because while they were being dropped several boats were engaged in pulling another boat off of the rocks in the vicinity of our detectors. They made entirely too much noise for our equipment to hear through. The records of mine drops A and B in the west channel were poor because insufficient gain was used in our amplifiers. To get the good record of Figure 14, gains over 40 db higher than that used for recording explosions from Danbuoy Easy had to be used. This was 6 db more gain than was used for getting the record from the more distant splash south of the point.

Figures 15 and 16 show the sound source bearings indicated by the two systems. This data was drawn on a map of the area which shows an outline of the southern end of Jamestown Island. Whale Rock and the light house on Beavertail Point are two reference landmarks accurately located from other maps. The circled points show where explosions produced signals for recording, and blacked in diamond shaped symbols show where mines splashed. The points from which the lines all emanate are the pickup locations. The arrows from these points indicate the orientation of the geophones. A sound from the arrow direction would produce a maximum positive signal on the V_y geophone and no signal on the other. The upper intensity trace (I_y) of each system would indicate the presence of this source. Sounds from other directions produce intensity components that vary as the cosine and the sine of the angle from the reference direction to the sound direction. The reference direction can be thought

of as "the detector north". The arrow on the map shows how it differed from true north. The lines on the maps through all the signal locations perpendicular to a line to the detectors are $\pm 5^{\circ}$ sectors of circles with their centers at the detectors. An indicated bearing crossing these lines is correct within $\pm 5^{\circ}$.

VI. DISCUSSION OF RESULTS

Several of the records demonstrate a feature of the intensity meter that seems to make it especially useful for studying sound propagation but interferes to a degree with accurate source location. Quite often during the tests more than one burst of energy from the source was detected. The bursts did not always arrive simultaneously nor was their direction of travel the same. Apparently these bursts were energy reflected or refracted from the bottom and the boulders along the shore as well as that traveling along the direct water path from the shot or splash point. As each burst arrived, it made a contribution to the intensity being measured and as a result the intensity traces had an irregular shape. These traces are actually records of the voltages across condensers which are charged in proportion to the sound intensity. A single energy burst quickly charges the condenser to a voltage that decreases exponentially after the energy flow has ceased. The arrival of another burst superimposes another sudden change and exponential decay on the voltage versus time curve and when numerous packets of energy pass the detector in a short period, the intensity trace on the record is not smooth. It has a bump for each packet of energy. When the bumps are sufficiently separated in time, each may be analyzed separately and the relative amplitudes and the travel directions of the energy pulses that caused them can be found. In this way various travel paths from the source to the detectors are indicated and compared. This is fundamental information on sound propagation that would be difficult to obtain in other ways. From the standpoint of locating the original sound source,

detecting more than one energy burst is undesirable unless the energy traveling in the direct path can be positively identified.

In the tests reported here, this identification was impossible. Since there are conceivable paths through the bottom formations in which acoustic energy travels faster than in water, the direct pulse will not necessarily arrive first. Information for identifying it on the basis of wave shape or frequency content in the pass band of our system was not available. For these reasons the assumption was made that less attenuation would occur in the direct path and that most of the total energy that flowed would be in the direct path. In keeping with this assumption, measurements on the intensity traces used for finding bearings were made during the final exponential decay period in every case. When the intensity curves were smooth, indicating that only one appreciable energy impulse was received, the records were considered good. Records showing the arrival of several impulses were of inferior quality because the bearing calculations are influenced by the minor impulses probably not traveling in the correct direction.

Two records of shots from Danbuoy Dog are presented in Figures 6 and 7. They show the repeatability of the data and also illustrate the type of data obtained when several energy bursts pass the detectors. In Figure 7, intervals during which discreet pulses were received were marked off. Only system 2 was considered but comparable intervals can be selected on system 1; they can also be observed on the record of Figure 6.

During interval "A" a pressure signal well above the ambient noise level arrived but practically no horizontal particle velocity accompanied it, so no horizontal energy flow was indicated. This seems to indicate a vertically traveling impulse. It could have been traveling up from the bottom or down from the surface. At the beginning of interval "B" horizontally traveling energy arrived. During the interval the condenser voltages reached a peak value proportional to the intensity components at pickup number 2 and started to decrease exponentially. At the beginning of interval "C" additional charge was placed on the condensers when another energy impulse with a horizontal component of travel arrived. The deviation of the intensity curves from exponential shows that this last impulse was smaller than the previous one and it arrived from a different direction. The second peak in the intensity curve is followed by an exponential decay. This interval is terminated by another barely perceptible impulse. This one was not recorded with sufficient sensitivity to find out much about it. Measurements for calculating the indicated bearing to the sound source were made during the exponential decay part of interval "C". Total deviations of the intensity traces from their zero positions were measured at an arbitrary instant in the interval. The ratio of these amplitudes was considered to be the tangent of the relative bearing angle to the source. This measurement would be expected to be in error because it is appreciably affected by at least two impulses which arrived from different directions. All records with irregular intensity curves such as these were considered poor.

The records of Figures 10, 11, and 14 were of much better quality. On them there was very little evidence that energy from the explosion or splashes arrived from more than one direction. Calculations gave this direction.

Most of the indicated bearings of Figures15 and 16 were calculated by measuring intensity trace deviations. Exceptions were those from mine drops "A" and "B" in the West Channel between Beavertail Point and the mainland. On these records the intensity recording sensitivity was too low to get any measurements, but the signal from the splashes could be seen on the velocity traces. In these cases bearings were calculated from measurements of the relative amplitudes of the velocity signals.

Attempts were also made to calculate bearings from delay times measured from the records. Extremely inaccurate results were blamed on difficulty in picking exact arrival times and on the relatively close spacing of the detectors. It was not felt that the data we had justified drawing conclusions on the comparative accuracy of the two methods for finding bearings but it did show that making accurate time delay measurements would be quite difficult when spaced pressure detectors operating in the frequency band between 50 and 400 cps are used.

Relative bearings to the sound sources were also indicated on the oscilloscopes. These indications, however, were short lived and were not successfully recorded. When a steady sound causes energy flow past the detectors, a line is produced on the oscilloscope which indicates the bearing to the sound source. When there is no net energy flow the line degenerates

to a point in the center of the screen. An impulse of energy such as that caused by the splashes studied made the spot dart out briefly in the correct direction but it returned to the center before an accurate reading could be taken. For a few of the splashes and explosions, the oscilloscope face was photographed while the spot was out in the correct direction but the pictures were improperly processed and faded out. For this reason they are not presented. While they lasted, the photographs provided a method of finding relative bearings without numerical calculations and therefore were preferable to the time records from the standpoint of finding bearings. In operational splash locating equipment, this photographic recording method can probably be used and time recordings such as the ones presented here would be unnecessary unless signal wave shapes are required for identifying mine splashes.

To find true sound source bearings from intensity measurements, the orientation of the detectors has to be known. Finding out what it was during these tests was one of the major problems of the operation. The tripod assemblies were lowered to the bottom on a single line which permitted them to rotate and assume an indeterminate orientation when they landed. Attempts to determine the orientation by observing the indicated bearing to a boat making noise at a known location were unsuccessful. The orientation found this way changed when the boat location changed. Energy reflected from the shore probably interfered with these measurements. Another attempt to determine the orientation was made by a diver who tried to get it by sighting along part of the tripod while it was in place. Murky water and the other conditions under which he was

forced to use the underwater compass made these measurements very unreliable.

The detector orientations indicated in Figures 15 and 16 were determined by an indirect method. Relative bearings were calculated from every record. The differences between these angles and the true azimuth angle to the source were then plotted as a function of the true bearing. A curve through these points should have been a straight line with zero slope, and the orientation of the detectors would have been the ordinate of the points on the line. In other words, the same correction should be applied to every indicated relative bearing to get the true bearing. These plots are shown in Figures 17 and 18. The dotted horizontal lines are the orientations assumed for the detectors. In drawing these "average" lines most weight was given the points obtained from "good" records. The explosion and splash locations are identified along the abscissa for reference to the maps and records.

A comparison between Figure 17 on system 1 and Figure 18 on system 2 shows that most consistent results were obtained from system 2. Since the only difference between the two systems was the detector locations, it was presumed that reflections from the shore were affecting the operation of the closer system, system 1, more than they were system 2. This was further supported by the fact that most of the bearings indicated by system 1 erred in the direction of the shore. We believe energy reflected from the shore combined with that in the direct path to produce these errors.

Since the indications of system 1 were not considered reliable because of shore effects, no effort was made to find the specific locations of the sound sources. Even if the shore had had no effect on the indications, locations would not have been accurate because of the close spacing of the detectors.

Additional support for the contention that the shore had more effect on system 1 than on system 2 is given by the record of Figure 14. On this record a wave breaking on the shore almost prevented getting a record of the splash on system 1, but the breaker only slightly effected system 2. The wave and splash signals are identified in the figure. The early intensity variations are attributed to a breaker principally because of the direction of travel of the sound wave producing them. It obviously arrived at the number 1 detector first. The later sound pulse which caused the second set of intensity variations arrived at the outboard detectors first. The fact that the two impulses arrived from opposite directions is clearly indicated also by the intensity traces of system 1. The direction of the breaks in the two traces was opposite for the two energy bursts. Interference such as this from breakers was encountered on system 1 but not on system 2 throughout the tests. It was usually eliminated by filtering in the system 1 signal amplifiers.

Figure 14 also illustrates an advantage of measuring intensity. The pressure traces (the top one and the fourth one down) show all the information that would have been obtained using only pressure detectors.

It seems unlikely that one could have distinguished between the breaker and the splash signals. The intensity traces, however, readily show distinguishing features.

Figure 11 is a good demonstration of another advantage of measuring intensity. Compare the signal-to-noise ratio on the pressure and velocity traces with that on the intensity traces. The improvement is marked. The noise recorded on the upper traces is believed to have been caused by boats in the vicinity of our detectors. While producing pressure and velocity variations that tend to mask the desired signal, they produced a steady intensity which did not obscure the variation caused by the mine splash. Similar improvement in signal-to-noise ratio can be noticed on most of the records, but noisy boats were not present in every case.

VII. CONCLUSIONS

The main conclusions reached as a result of the tests are that the intensity meter can be used to find the bearing of splashes and that it would probably be useful for studying sound propagation, especially in situations complicated by several reflectors. The bearing accuracy from intensity measurements appears to be better than 5° when good records are obtained, and intensity measurements seem to give information on the direction of travel of energy impulses that would be very difficult to obtain otherwise. The improvement in signal-to-noise ratio demonstrated on several of the records shows that satisfactory detection of transient signals is possible even when the steady background noise level is high.

In general, these conclusions had already been reached from theoretical considerations. It was gratifying that the tests confirmed them.

The tests also indicated how important it is to have the detectors planted well away from the shore and other reflectors. Data from the number 1 system were not considered reliable because the detectors were too close to shore and they were practically neglected in making conclusions on the accuracy of the scheme.

VIII. RECOMMENDATIONS

This work also suggested instrumental changes that would improve the system and further tests that would be necessary for a complete evaluation.

Instrumental changes would include automatic gain control in the amplifying and multiplying units and provisions for automatically recording received transient signals. The automatic gain control would increase the percentage of records which had signal deviations that could be measured accurately. It would prevent over driving from nearby splashes and would insure satisfactory recording of distant ones. Small signal variations occurring after receipt of the initial energy burst might also be brought out and be made more useful by proper gain variations. This technique is successfully employed in seismic prospecting for oil and would probably be profitable in this application. Automatic recording would make the system suitable for continuous monitoring. An impulse sensing trigger system could be designed so that when a transient signal similar to that caused by a splash is received an alarm would be energized and the recording system standing by would be started to record the transient. These two features, gain control and automatic recording, would make it unnecessary for an operator to be in attendance when splashes occur. The recorded data could be interpreted later when proper defensive action is in order.

Before widespread use of the intensity meter for locating splashes could be recommended more complete evaluation is necessary. All the possible factors affecting the system operation not studied during these

tests should be investigated and data on many more splashes should be obtained. This is necessary for positively evaluating the reliability and accuracy of the system. The results of the tests already conducted do suggest, though, that the more complete tests would confirm the opinion that this simple system would be reliable and accurate enough for almost any harbor defense application.

For propagation studies in which the time and place of the original signal is under control, the instrument appears to be ready for use as it is. Perhaps automatic gain control to enhance weak pulses would be worth adding. Further tests will be necessary to confirm these possibilities, however, and they can be conducted as the instrument is used.

IX. SUMMARY

During the tests reported here, the ability of the intensity meter to point toward a transient source of sound was demonstrated. The small detectors, operating in the frequency band between 50 and 400 cps, did not have to be scanned or rotated to locate the source and clear bearing indications were obtained in the presence of large steady noises and when one sound impulse arrived at the detectors within approximately one-tenth of a second after another. The tests showed the instrument to be suitable for locating splashes from aerially laid mines and for studying sound propagation. Successful pointing in the travel direction of energy impulses suggests that the instrument can also be used in other applications - as a receiver in a low frequency sonar system for example.

X. APPENDIX

APPENDIX

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FIGURE 1
SKETCH OF TRIPOD ASSEMBLY

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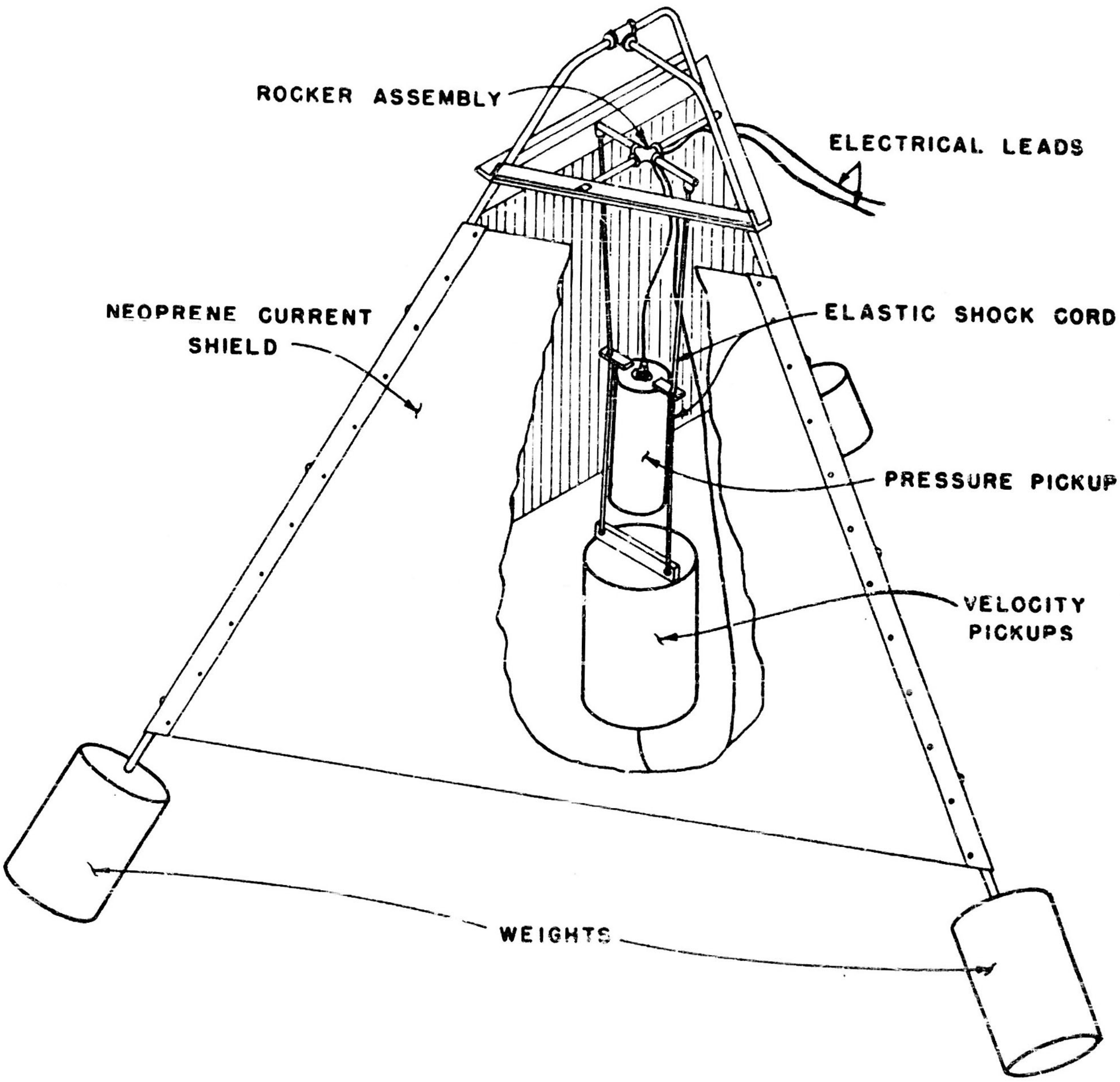

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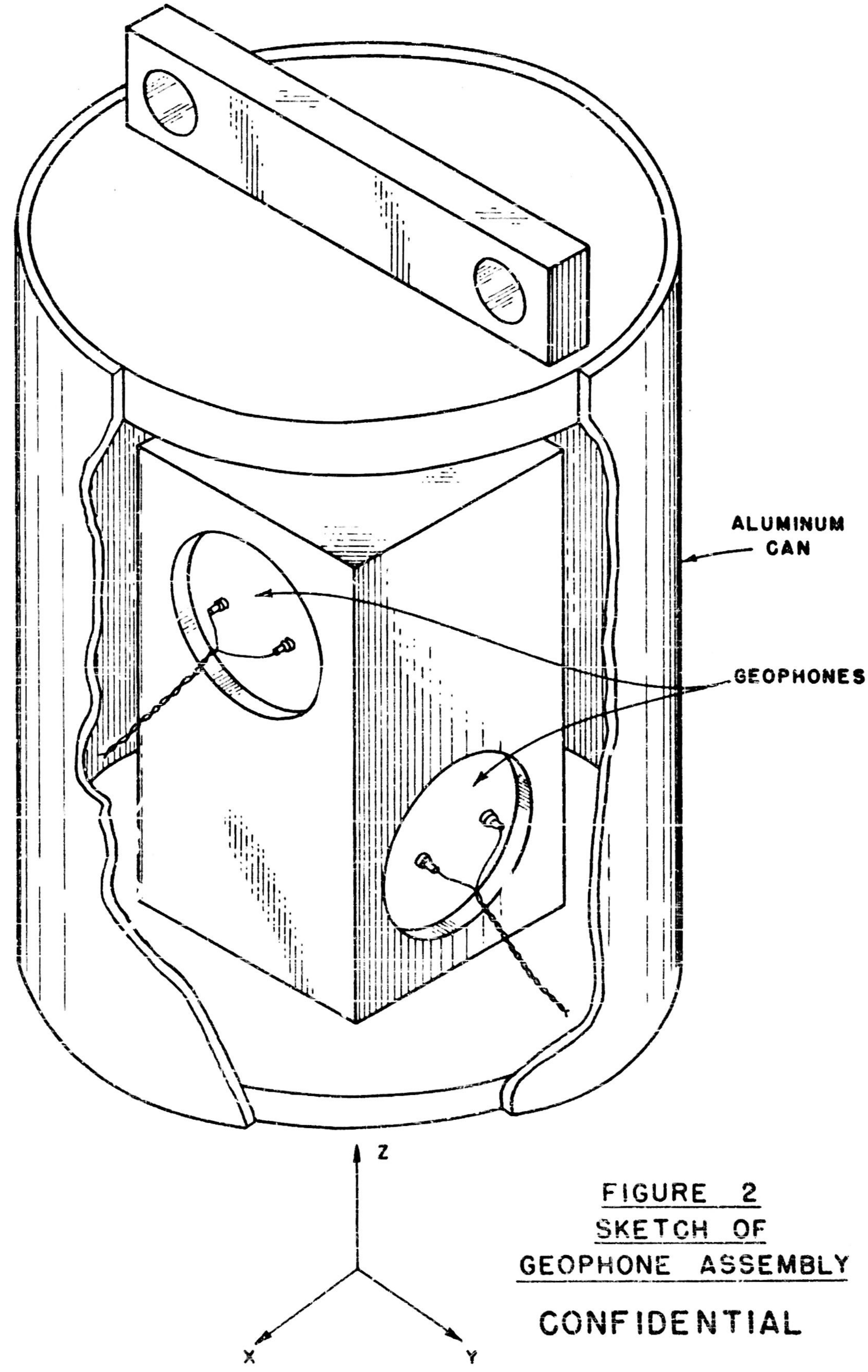

FIGURE 2
SKETCH OF
GEOPHONE ASSEMBLY

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FIGURE 3

BLOCK DIAGRAM OF INSTRUMENTATION

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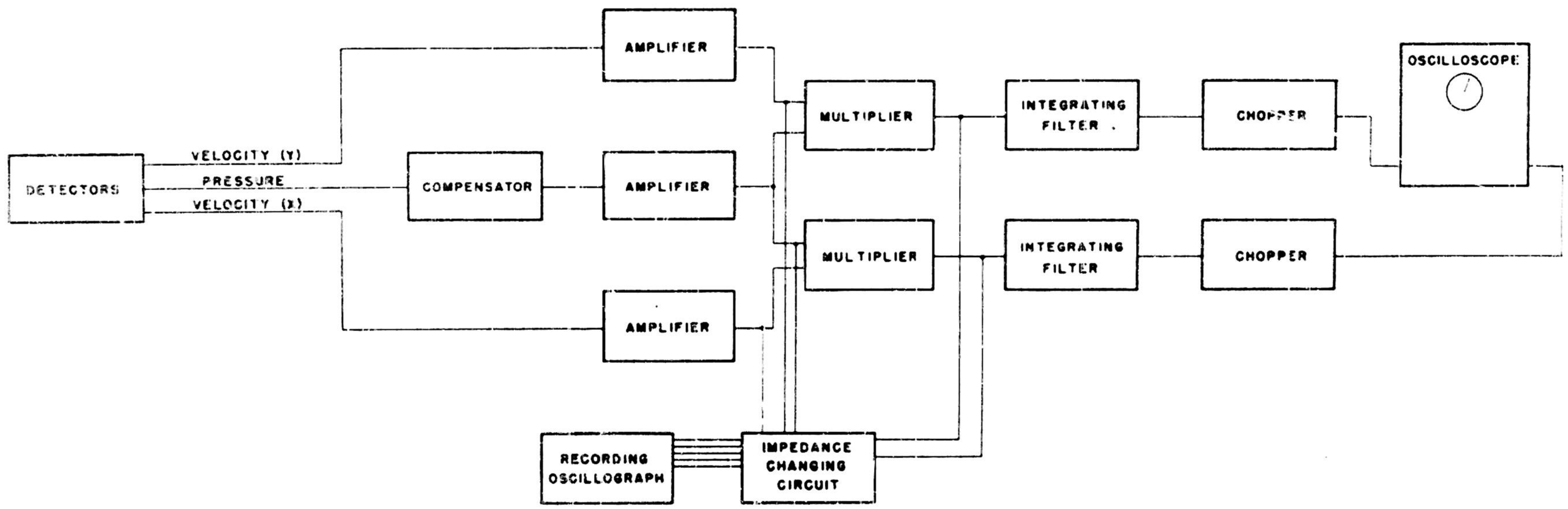

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FIGURE 4

TYPICAL RECORD OF DYNAMITE CAP EXPLOSION AT T-21

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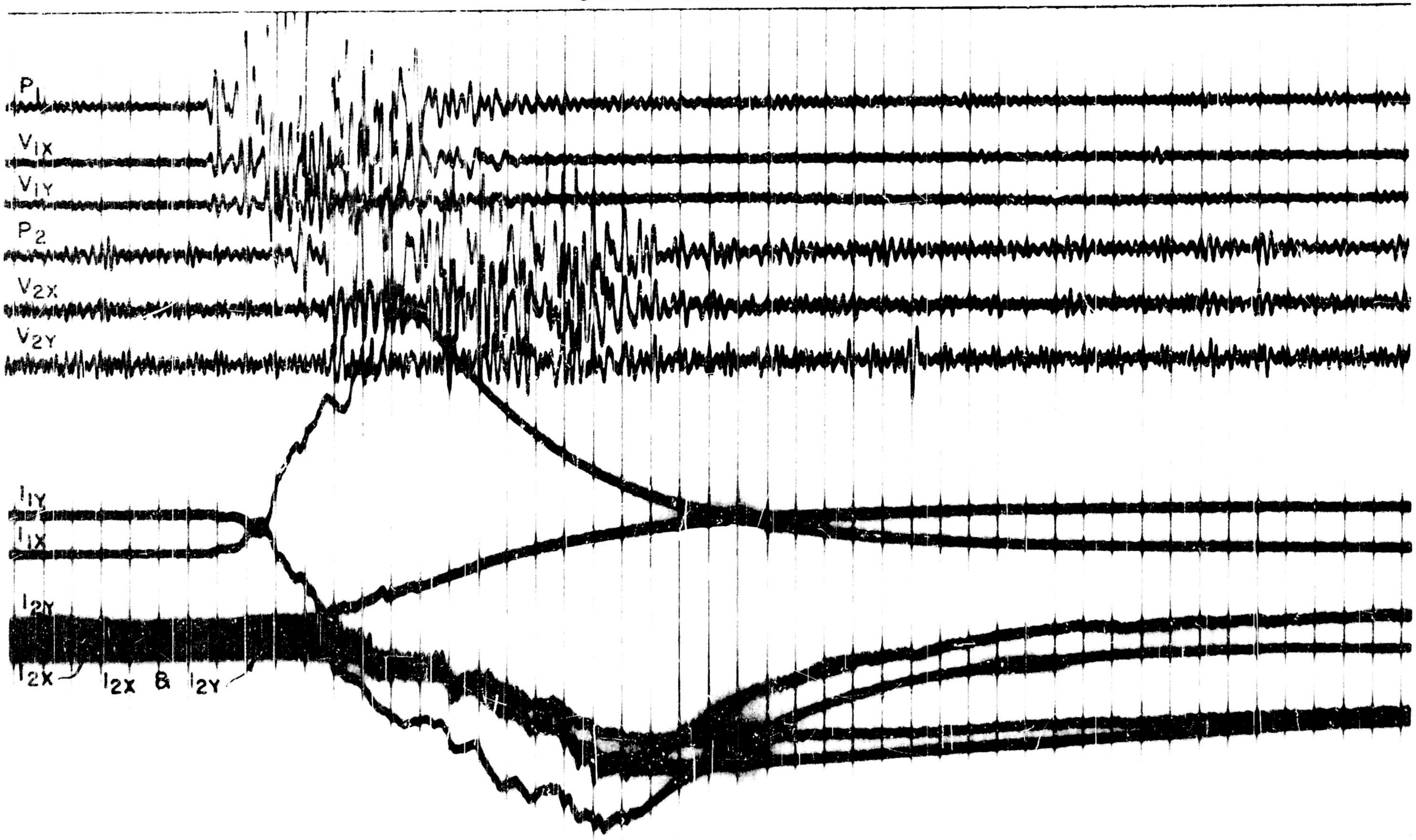

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FIGURE 5

TYPICAL RECORD OF DYNAMITE CAP EXPLOSION AT T-21-S

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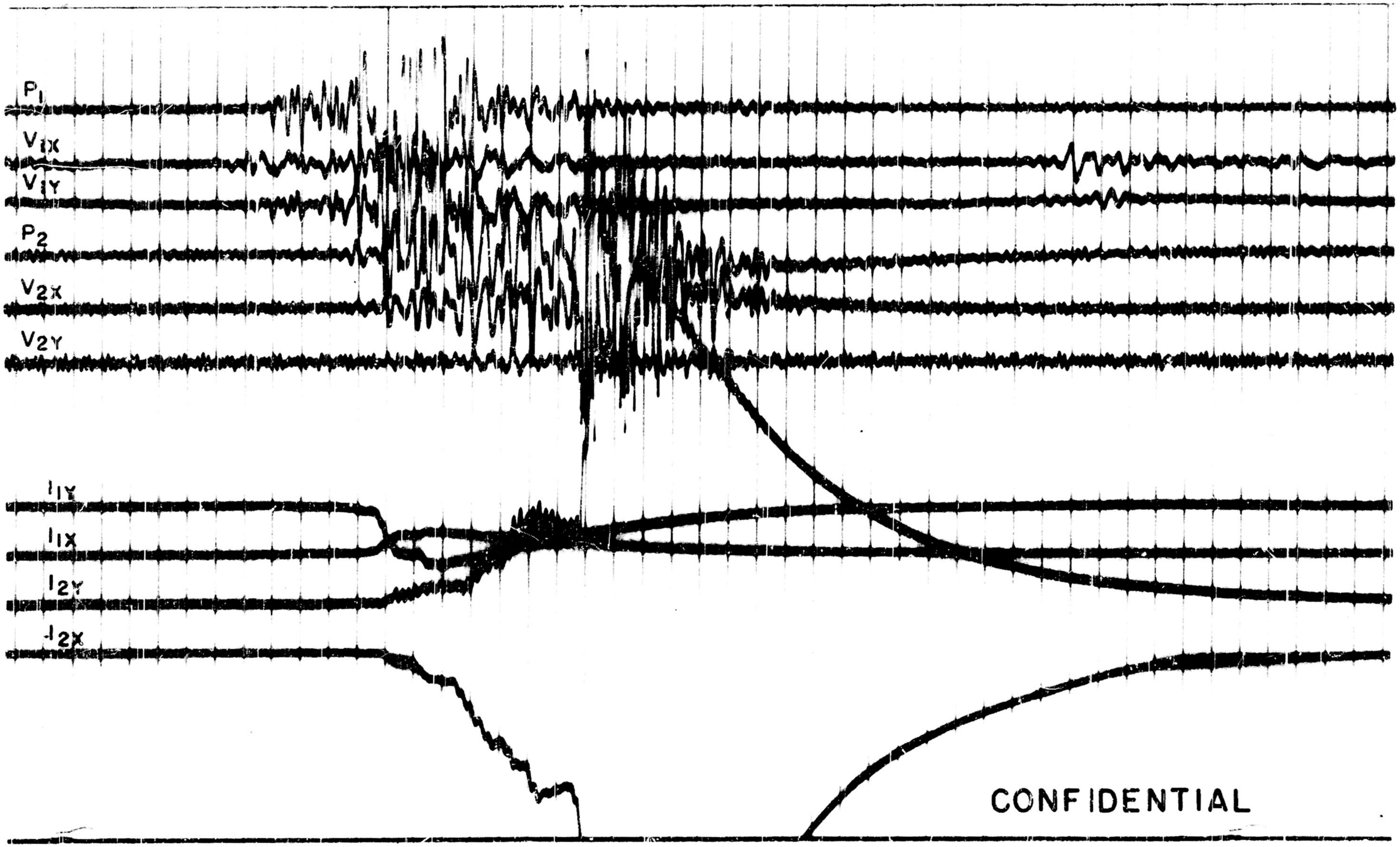

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FIGURE 6

TYPICAL RECORD OF DYNAMITE CAP EXPLOSION AT DANBUOY DOG

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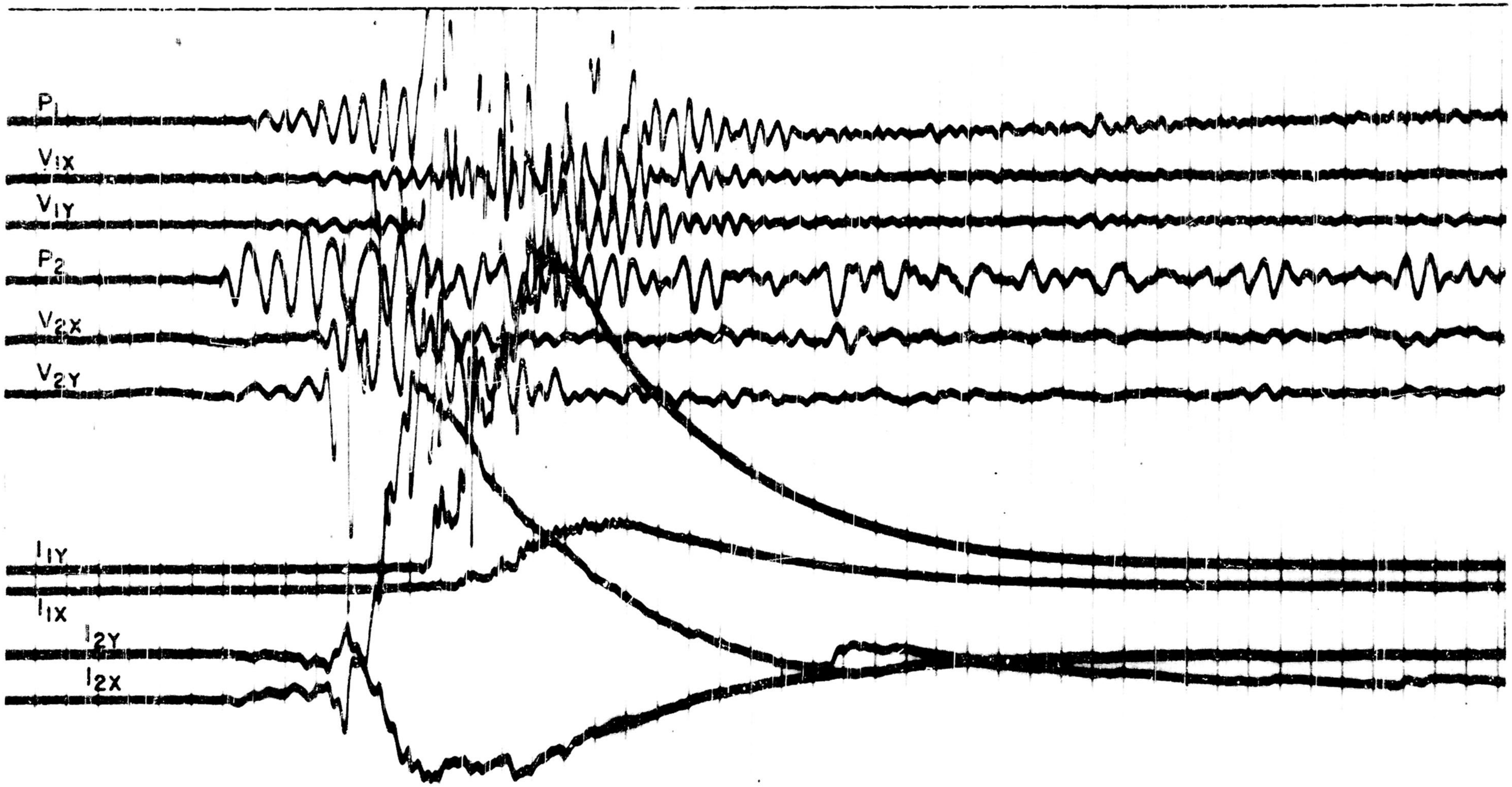

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FIGURE 7

TYPICAL RECORD OF DYNAMITE CAP EXPLOSION AT DANBUOY DOG

CONFIDENTIAL

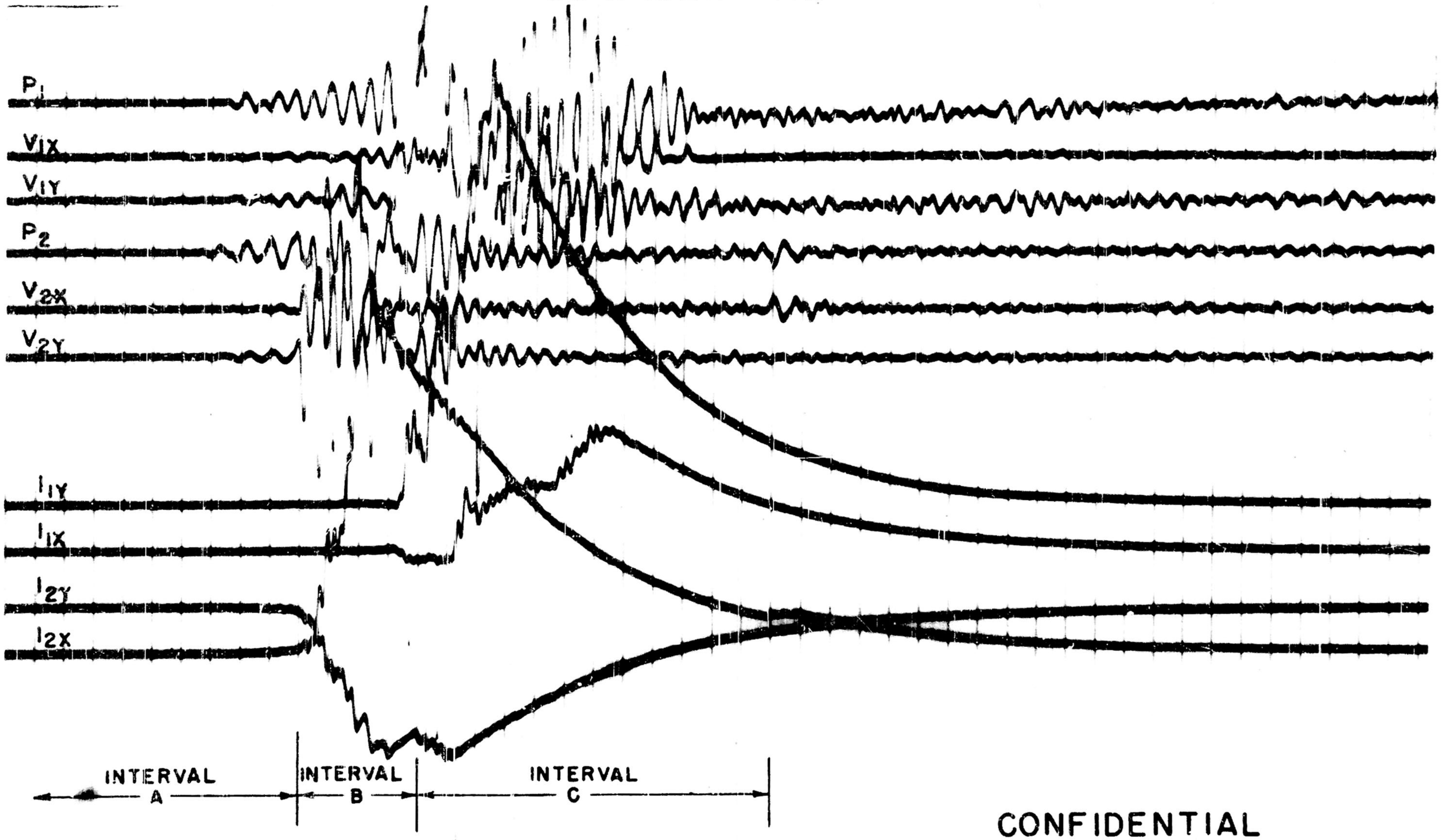

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FIGURE 8

TYPICAL RECORD OF DYNAMITE CAP EXPLOSION AT DANBUOY EASY

CONFIDENTIAL

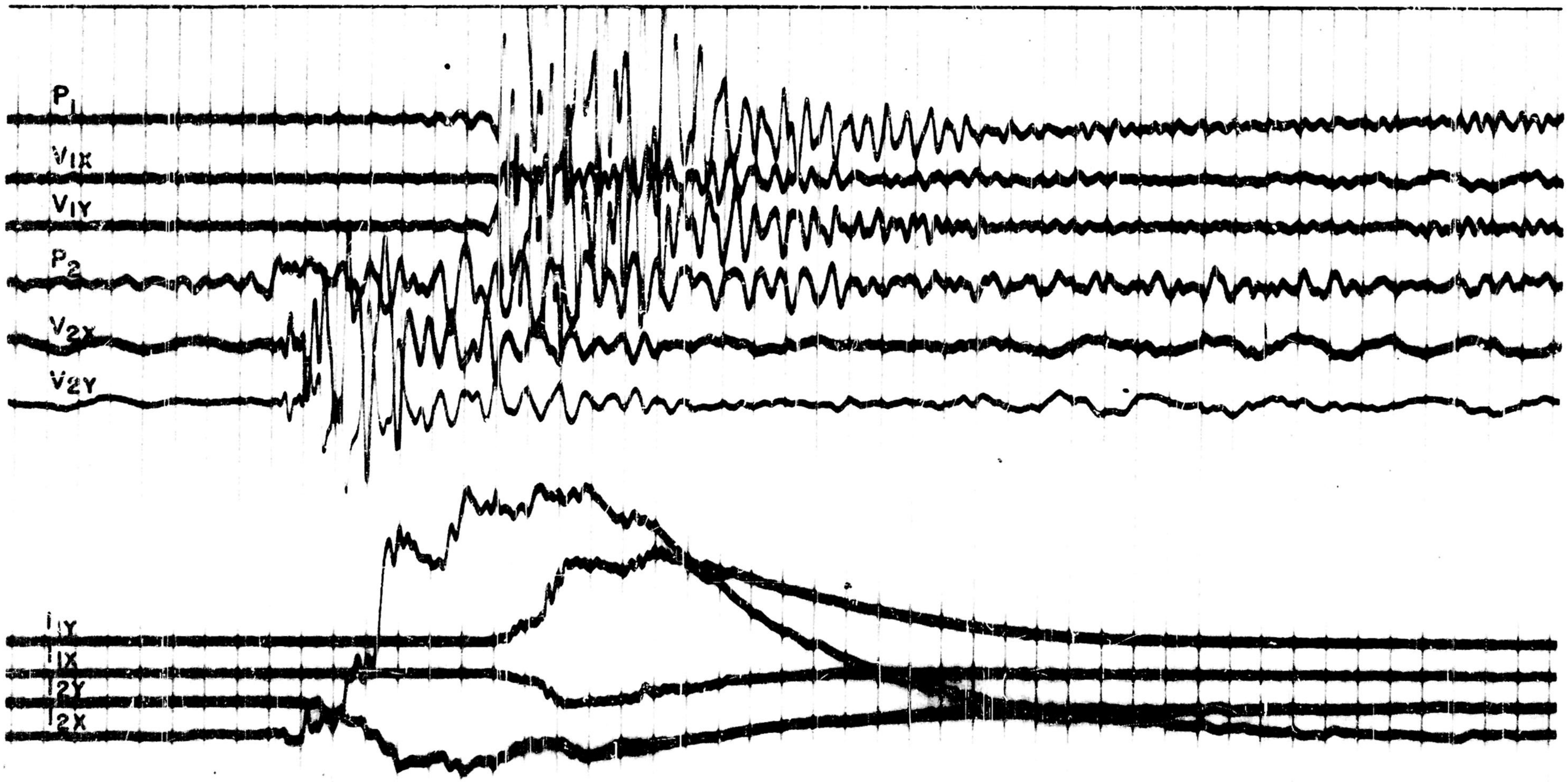

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FIGURE 9

TYPICAL RECORD OF DYNAMITE CAP EXPLOSION AT DANBUOY FOX

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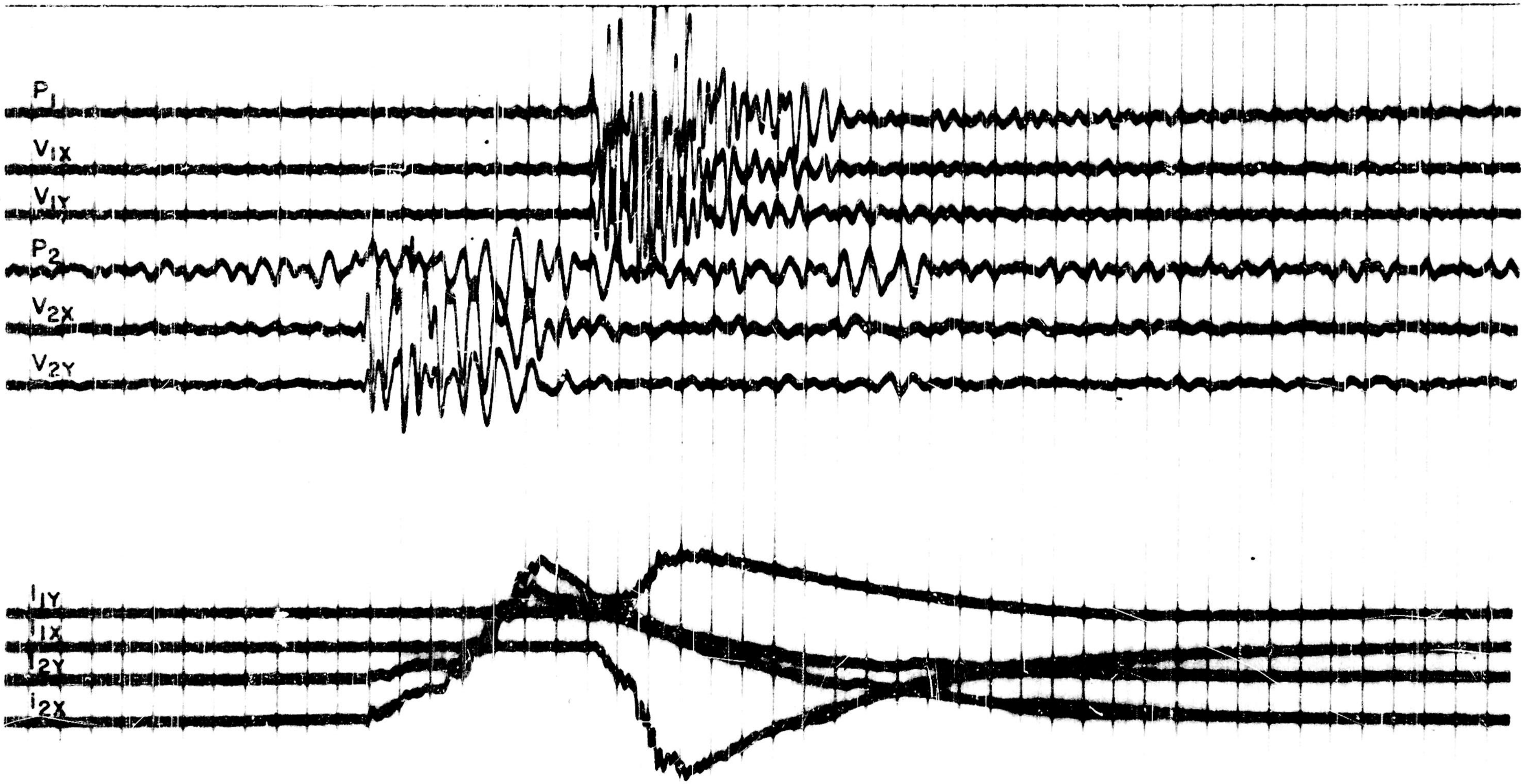

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FIGURE 10

DYNAMITE CAP EXPLOSION AT "GETTY"

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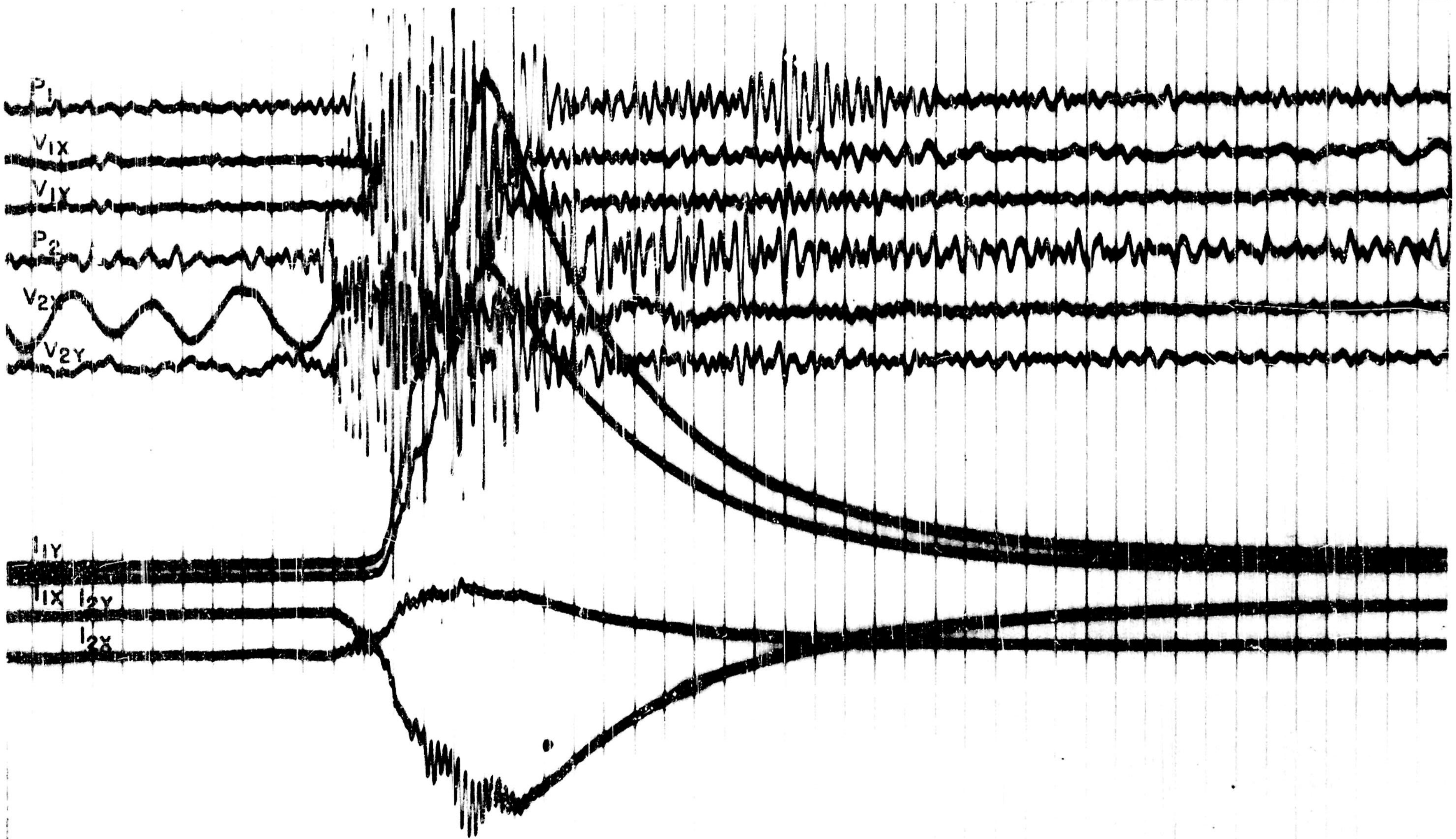

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FIGURE 11

MINE DROP SOUTHWEST OF BEAVERTAIL POINT

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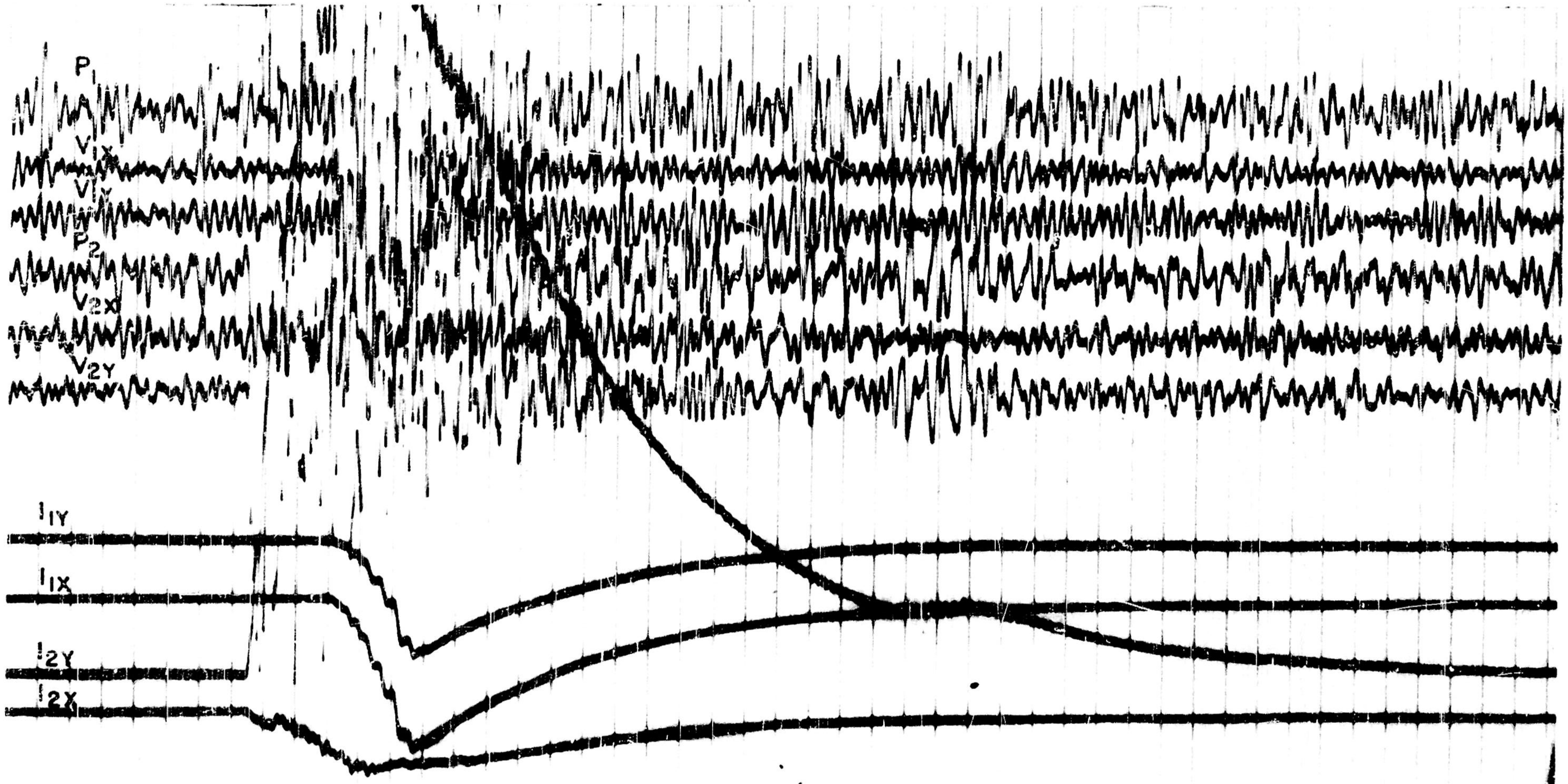

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FIGURE 12

MINE DROP A IN WEST CHANNEL

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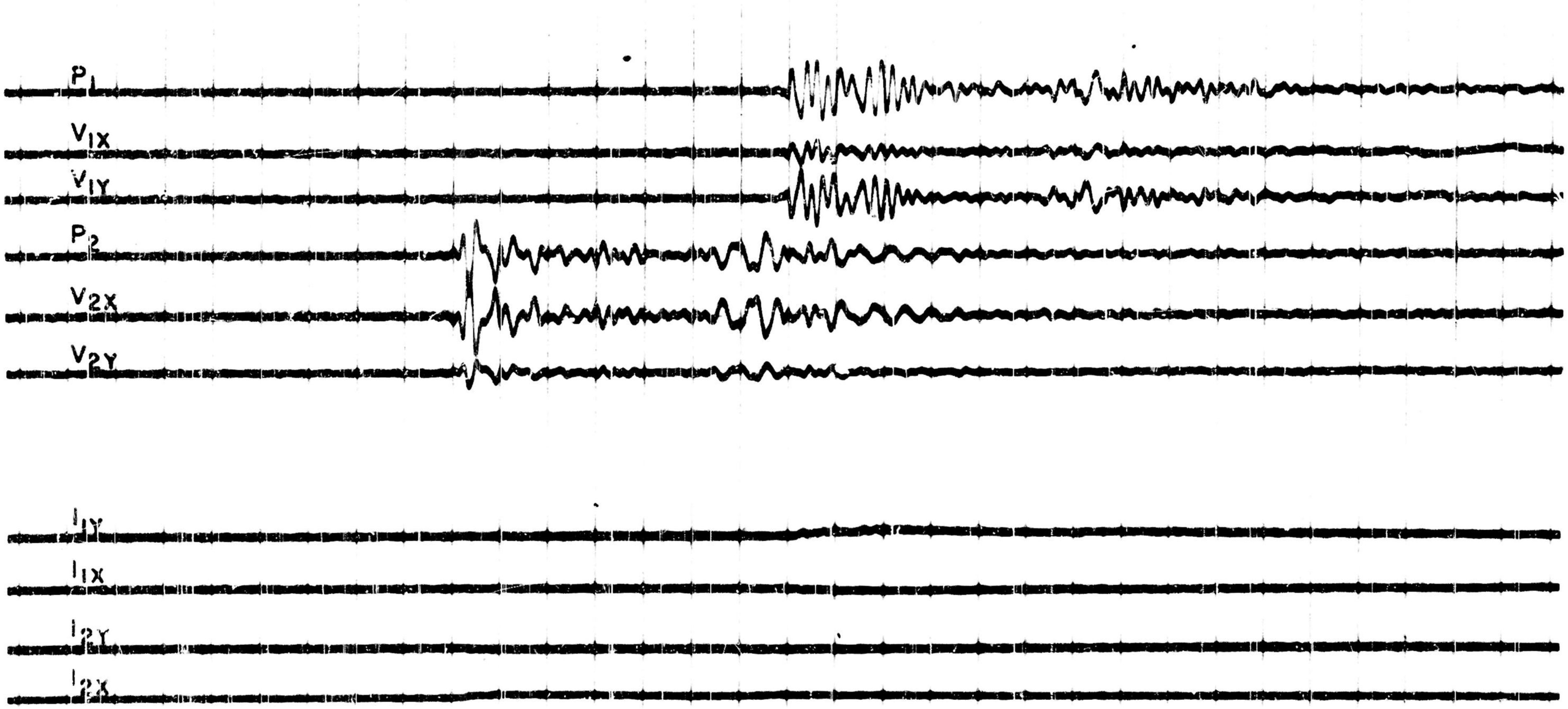

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FIGURE 13

MINE DROP B IN WEST CHANNEL

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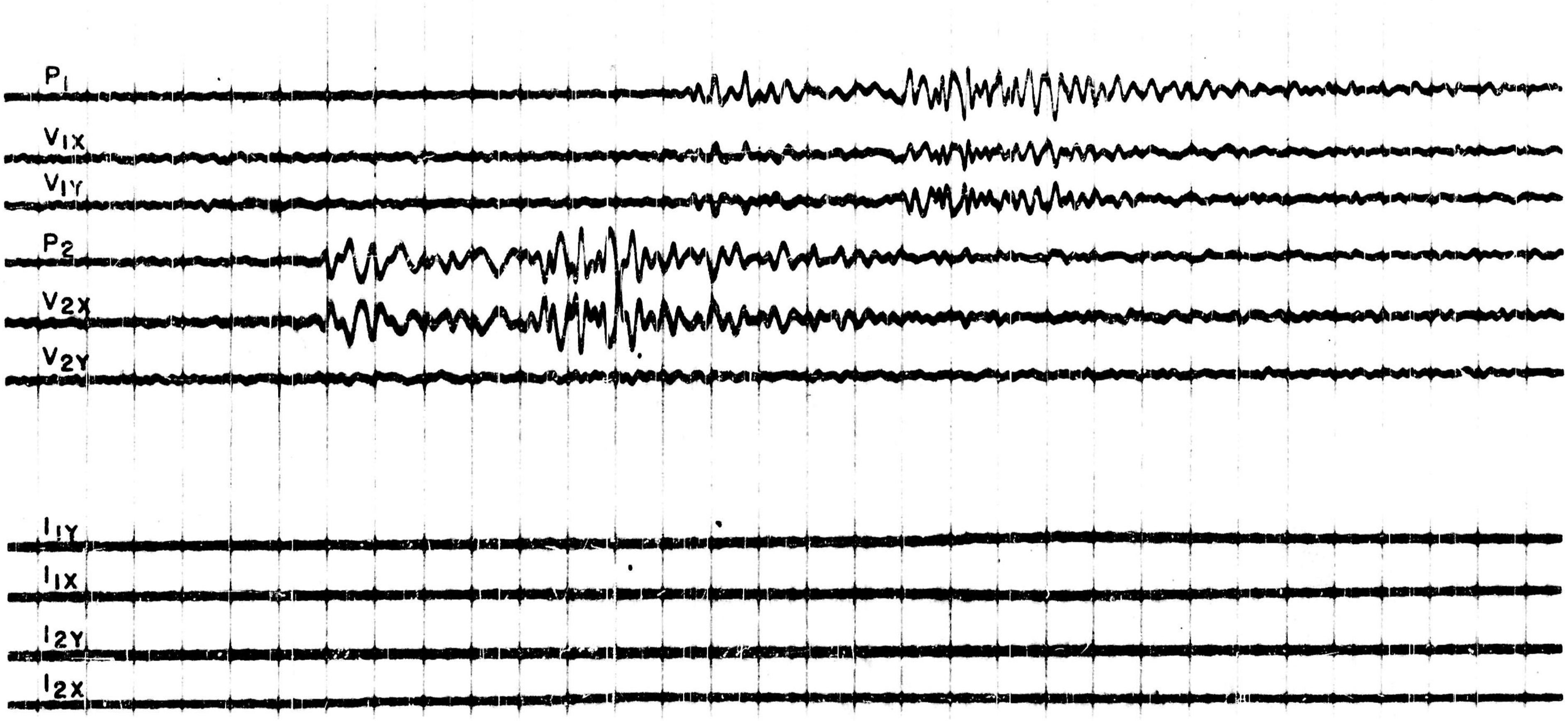

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FIGURE 14

MINE DROP C IN WEST CHANNEL

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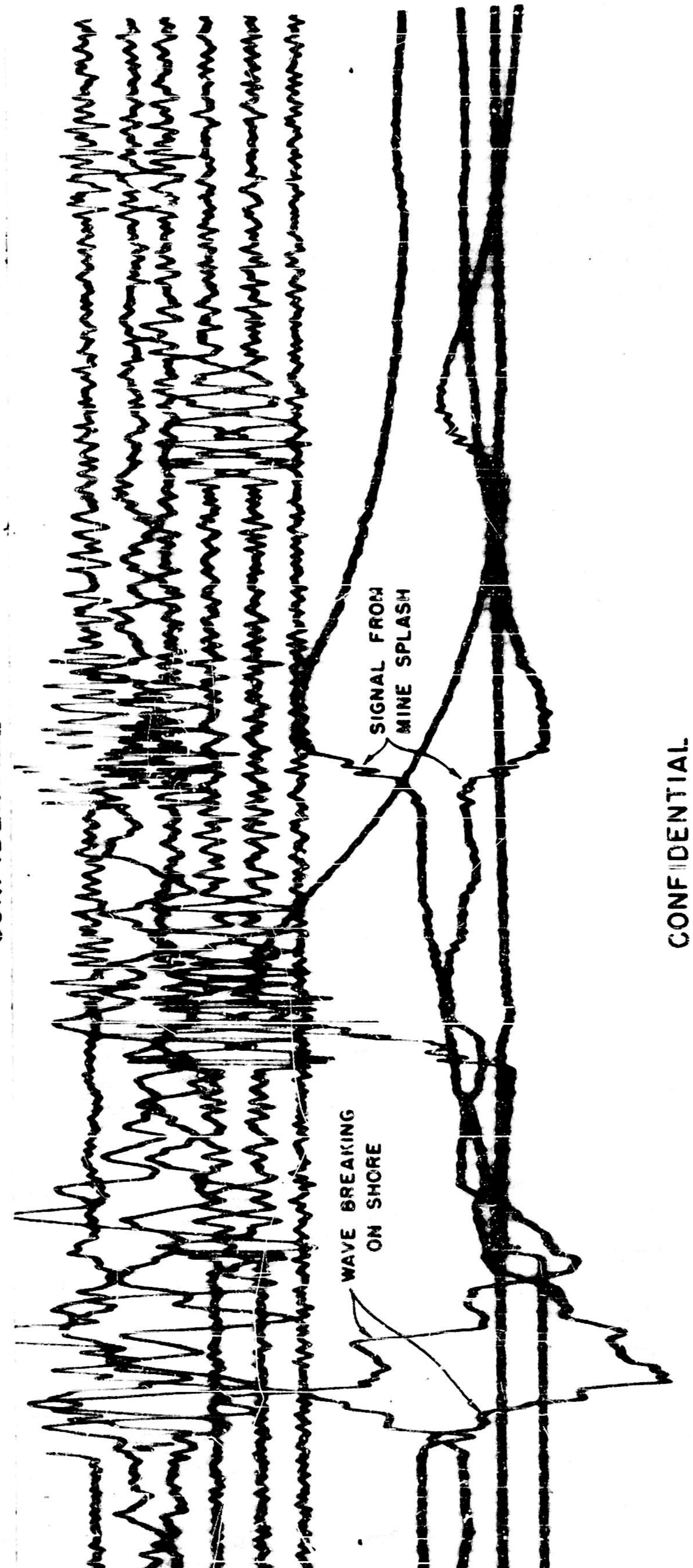

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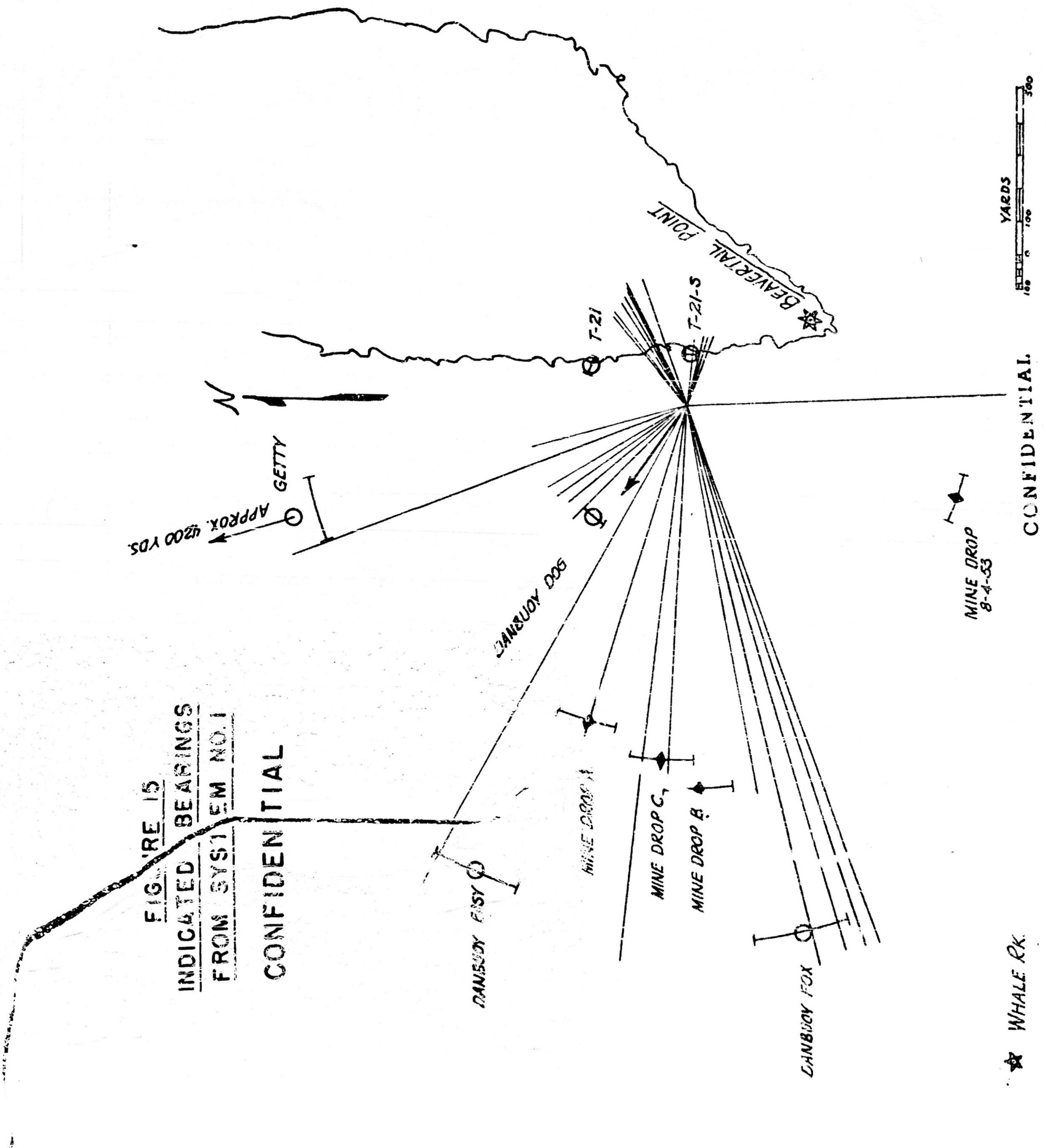

FIGURE 15
INDICATED BEARINGS
FROM SYSTEM NO. 1
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FIGURE 16
INDICATED BEARINGS
FROM SYSTEM NO. 2

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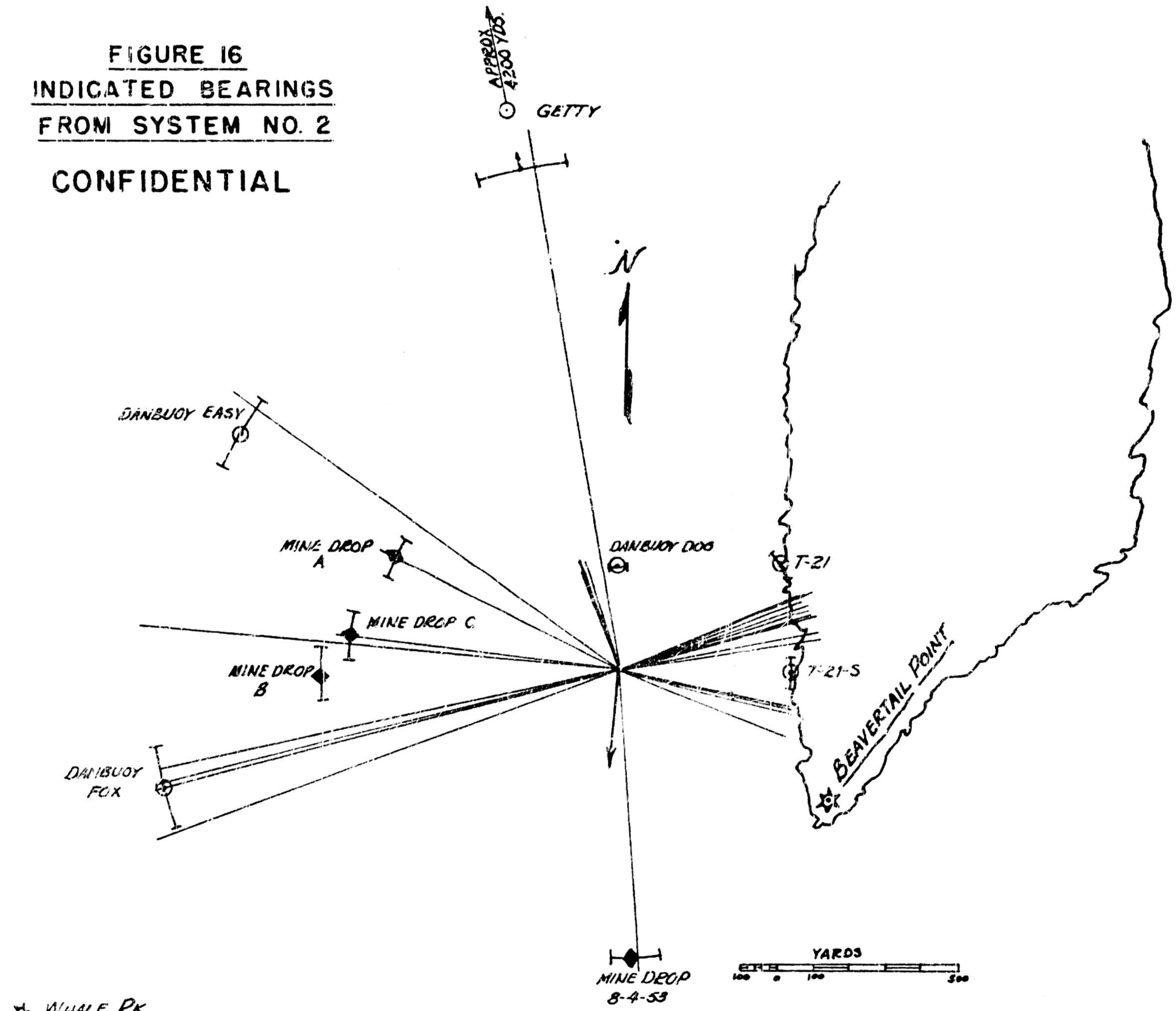

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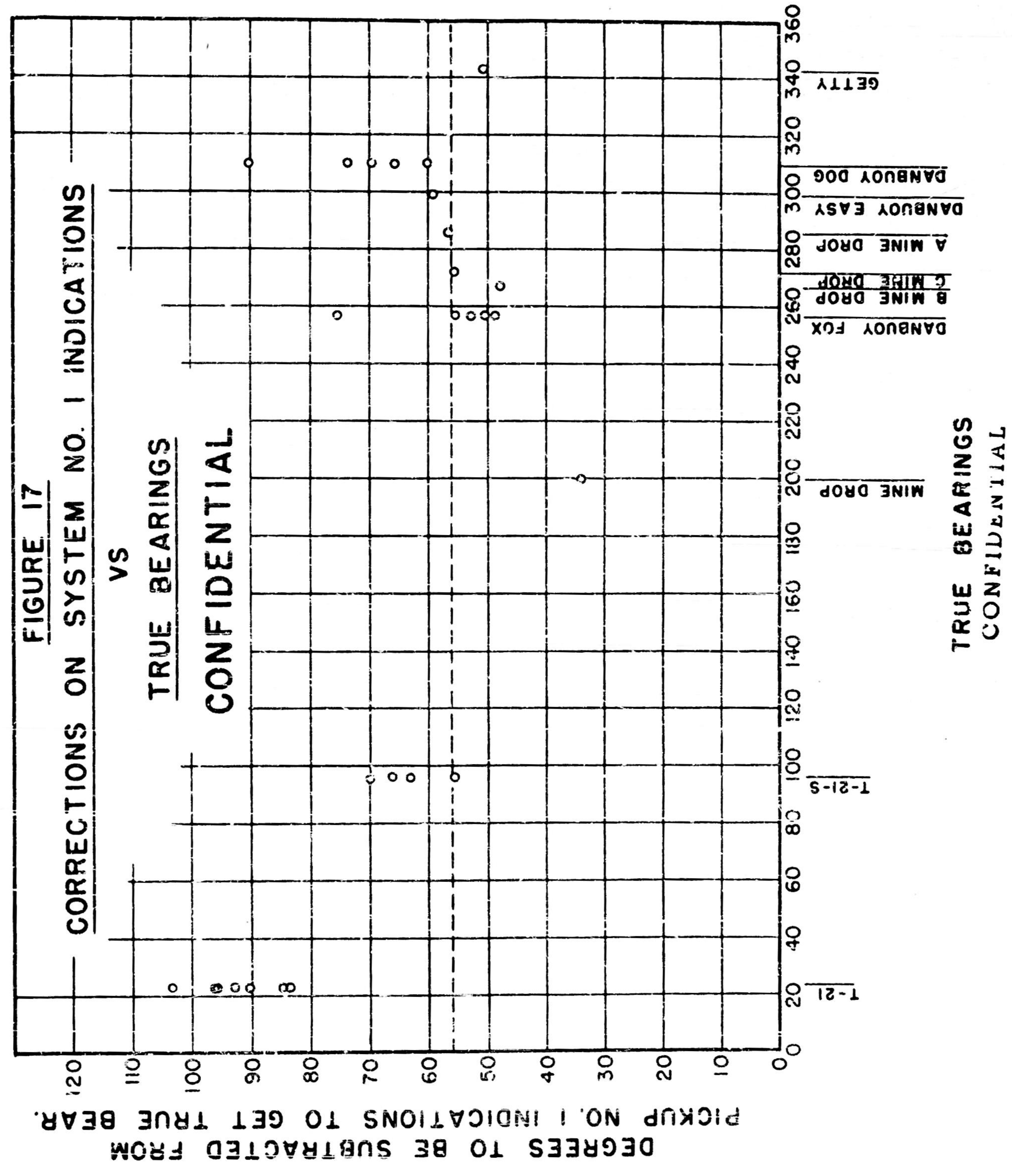

FIGURE 17

CORRECTIONS ON SYSTEM NO. 1 INDICATIONS VS TRUE BEARINGS

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FIGURE 18

CORRECTIONS ON SYSTEM NO. 2 INDICATIONS VS TRUE BEARINGS

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